[illegible]ON CYLINDER BRIDGE PI[illegible]

ON THE

[illegible] ATIONS AND [illegible]ESTIGATIONS NECESSARY

[illegible]M.

WITH

TABLES [illegible] [illegible] [illegible]

REMA[illegible] [illegible] AND [illegible] [illegible]YED.

JO[illegible] [illegible], [illegible] INST. C.E.

[illegible] A [illegible])

[illegible]D ON THE 25TH APRIL, 187[illegible], AT A SUPPLEMENTAL MEETI[illegible] OF THE STUDENTS OF THE INSTIT[illegible]ON OF CIVIL ENG[illegible]

And to which the Council awa[illegible] [illegible]ller P[illegible] [illegible]

LONDON:
E. & F. N. SPON, 48, CHARING CROSS.
NEW YORK:
446, BROOME STREET.
187[illegible]

IRON CYLINDER BRIDGE PIERS.

ON THE

CALCULATIONS AND INVESTIGATIONS NECESSARY
IN DESIGNING THEM,

WITH

TABLES FOR FACILITATING THE CALCULATIONS; FORMULÆ;
REMARKS ON FOUNDATIONS AND THE MATERIALS EMPLOYED.

BY

JOHN NEWMAN, Assoc. Inst. C.E.

BEING

A PAPER

(WITH ADDITIONS)

READ ON THE 25TH APRIL, 1873, AT A SUPPLEMENTAL MEETING OF THE
STUDENTS OF THE INSTITUTION OF CIVIL ENGINEERS.

And to which the Council awarded a Miller Prize. Session 1872-3.

LONDON:
E. & F. N. SPON, 48, CHARING CROSS.
NEW YORK:
446, BROOME STREET.
1875.

INDEX.

TABLES "A" AND "B."

FOR FACILITATING THE CALCULATIONS REQUIRED IN DESIGNING AN IRON CYLINDER BRIDGE PIER.

NOTE.—It is understood that the Institution of Civil Engineers, as a body, is not responsible for the facts and opinions advanced in this Paper.

ON THE

CALCULATIONS AND INVESTIGATIONS

NECESSARY IN DESIGNING

IRON CYLINDER BRIDGE PIERS.

THE author, being unable to find much information on "the Calculations and Investigations necessary in designing Iron Cylinder Bridge Piers," submits the following paper in the hope that it will be the means of eliciting a full discussion on the subject. He has compiled the Tables "A" and "B" with the object of facilitating the calculations required in designing the piers or abutments of a bridge, when the above system of foundations is adopted, and trusts that they may be found practically useful. Some few remarks are added on foundations generally and the materials employed in them.

Let us proceed to investigate the forces governing the stability of iron cylinder bridge foundations.

It is impossible to lay down invariable and rigid laws for their stability, on account of the suppositions that must be made as to the safe load per square foot on the earth at the base of the cylinder, and the support which it will receive from surface friction. When these coefficients are settled, the proper diameter of the cylinder can be arrived at. Existing examples, in similar situations, and in soils of the same nature as that of the structure to be designed, will be found to be the safest guide, and the designer cannot do better than refer to them.

THE SUPPORTING POWER IS DERIVED FROM—

1. The area of the base, which is as square of diameter.
2. The area of the surface in contact with earth, which varies as diameter and depth cylinder is sunk in ground.
3. The safe load per square foot on base, or bearing support due to internal sectional area of cylinder.

4. The safe load on frictional surface per square foot, or bearing support due to surface friction.
5. Flotation power, or loss of weight from immersion in water, which varies as square of diameter and depth of water.

NOTE.—In calculating the stability of cylinders of small diameter, the support derived from this source, or rather the loss of weight, may be omitted, as it amounts to practically *nil.*

THE NON-SUPPORTING POWER IS—

1. Weight of iron in cylinder.
2. „ concrete in cylinder.
3. „ brickwork in cylinder.
4. „ superstructure or load on cylinder from girder.

NOTE.—The first three items vary as the diameter and height of cylinder.

From the above it is obvious that the diameter of the cylinder is regulated:

1. By the weight superimposed (which varies as the span, width of roadway, load, and number of cylinders of which the pier consists).
2. By its own weight, which varies as its own height and diameter.
3. By the depth it is sunk in the ground.
4. By the resistance from friction of the ground on its surface.
5. By the safe load on base.
6. By its flotation power, or loss of its weight from immersion in water.

It is evident for the cylinder to be stable that the safe load on base + resistance from friction of ground on its surface + the flotation power must equal weight superimposed + weight of cylinder complete.

Expressed Algebraically.

Let S = Safe load on base of cylinder.

„ R = Resistance from friction of ground on surface of cylinder.

Let F = Flotation power or loss of weight of cylinder from immersion in water.
„ W = Weight superimposed.
„ C = Weight of cylinder complete.

Then for cylinder to be stable,

$$S + R + F \text{ must equal } W + C.$$

The following is a calculation in detail for the proper diameter of a cylinder in a supposititious case.—

Data.—Span, 120′ 0″. Single line of railway. Two cylinders, each supporting one main beam. Cylinder to be sunk 24′ 0″ in ground. Height of cylinder above bed of river 30′ 0″. Total height of cylinder, 54′ 0″. Thickness of cylinder $1\frac{1}{4}''$ for 30′ 0″ high. Thickness of cylinder $1\frac{1}{2}''$ for 24′ 0″ high. To be filled with Portland cement concrete from bottom to ground line, and from ground line to top with brickwork in cement.

Greatest pressure on ground at base of cylinder not to exceed five tons per square foot.

Resistance from friction on surface not to be calculated as more than one-fifth of a ton per square foot.

Lowest depth of water known = 7′ 0″.

NON-SUPPORTING POWER.

Approximate weight of cast iron in cylinder 8′ 0″ diameter, $1\frac{1}{2}''$ thick for 24′ 0″ high (depth sunk in ground).

$$\begin{aligned} & & &\text{cube ft.}\\ 8{\cdot}25^2 \times {\cdot}7854 &= &&53{\cdot}45\\ 8^2 \times {\cdot}7854 &= &&50{\cdot}26\\ \hline & &&3{\cdot}19 \times 24' = 76{\cdot}56 \text{ cube feet cast iron.}\\ 76{\cdot}56 \times {\cdot}20 &= &&15{\cdot}31 \text{ tons.}\end{aligned}$$

Approximate weight of cast iron in cylinder, 8′ 0″ diameter, $1\frac{1}{4}''$ thick for 30′ 0″ high (ground line to top of cylinder).

$$\begin{aligned} & & &\text{cube ft.}\\ 8{\cdot}208^2 \times {\cdot}7854 &= &&52{\cdot}91\\ 8^2 \times {\cdot}7854 &= &&50{\cdot}26\\ \hline & &&2{\cdot}65 \times 30' = 79{\cdot}50 \text{ cube feet cast iron.}\\ 79{\cdot}50 \times {\cdot}20 &= &&15{\cdot}9 \text{ tons.}\end{aligned}$$

Summary of approximate weight of cast iron in cylinder.

		tons.
8′ diameter, $1\frac{1}{2}''$ thick, 24′ high	=	15·31
8′ " $1\frac{1}{4}''$ " 30′ "	=	15·90
		31·21
Joint flanges, ribs, lugs, strengthening brackets, bosses, stiffeners, bolts, &c., 25 per cent. ..		7·80
		39·01
Bracing frame to cylinder (say)		·99
		40·00

The author does not give a detailed calculation of the weight of joint flanges, &c., as it would take up so much space and be of no practical value.

NOTE.—In all cases the diameters mentioned are the *internal* diameters.

Approximate weight of concrete in cylinder.

yds. high.		area. sq. yds.		cube yds.		tons.		tons.
8	×	5·58	=	44·64	×	1·64	=	73·21

Approximate weight of brickwork in cylinder.

yds. high.		area. sq. yds.		cube yds.		tons.		tons.
10	×	5·58	=	55·80	×	1·35	=	75·33

NOTE.—The weight of a cube yard of Portland cement concrete is taken at 1·64 tons per cube yard, and a cube yard of brickwork in cement at 1·35 tons.

Summary of weight of cylinder complete:

		tons.
Cast iron	=	40·00
Concrete	=	73·21
Brickwork	=	75·33
Bedstones, &c. (say)	=	1·46
Total		190·00

Approximate weight of superstructure:

		tons. per ft. run.
Girders, including cross-girders, rollers, roller-beds, &c., 120′ span, weigh 75 tons	=	·625
Roadway planking, 14′ × 6″ × 1′ = 7 c. ft. × 45 lbs. = 315 lbs.	=	·150
Carried forward		·775

Permanent way and ballast:

Brought forward		·775
2 lineal feet of rails, at 72 lbs. per yard	=	·022
2 longitudinal sleepers, at 25 lbs. per foot	=	·022
Ballast 4″ thick, 14′ × 1′ × 4″ = 4·66 cube ft. × 150 lbs.	=	·312
Total weight per foot run of span	=	1·131
Test load " " "	=	1·500
Total weight of superstructure		2·63 tons per foot run.

Weight of superstructure on one cylinder (test load included) .. .. .. $= \dfrac{120 \times 2 \cdot 62}{2} =$ 158 tons.

Weight of cylinder, complete, as above .. .. = 190 "

Total weight on cylinder, including its own weight and test load .. .. .. = 348 "

Supporting Power.

From area of base:

$$8^2 \times \cdot 7854 = \overset{\text{area.}}{50 \cdot 27} \times \overset{\text{tons.}}{5} = \overset{\text{tons.}}{251 \cdot 35}$$

From surface friction:

$$8 \cdot 25 \times 3 \cdot 1416 = \overset{\text{circumf.}}{25 \cdot 92} \times \overset{\text{height.}}{24} = \overset{\text{sq. ft.}}{622 \cdot 08} \times \overset{\text{tons.}}{\cdot 20} = 124 \cdot 42$$

From immersion in water:

$$8 \cdot 208^2 \times \cdot 7854 = \overset{\text{area.}}{52 \cdot 91} \times \overset{\text{depth of water.}}{7} = \overset{\text{cube ft.}}{370 \cdot 37} \times \overset{\text{lbs.}}{62 \cdot 4} = \overset{\text{lbs.}}{23{,}111} = 10 \cdot 32$$

Total supporting power .. .. .. 386·09

	tons.
Supporting power	386
Weight of cylinder, complete, and superstructure on one cylinder (test load included)	348
	38 tons excess of supporting power.

Weight on cylinder:

		tons.
Weight of cylinder, complete .. .. =		190
Weight of girder and roadway $= \dfrac{120 \times \overset{\text{ton.}}{1 \cdot 131}}{2} =$	68 tons.	
Usual moving load .. .. .. $= \dfrac{120 \times \overset{\text{ton.}}{1}}{2} =$	60	
		128
		318 tons.

Calculation showing weight to be supported by base, deducting surface friction at ·20 ton per square foot:

		tons.
Total weight, as next above	=	318
Deduct support derived from surface friction ..	=	125
		193 tons to be supported by base.

		sq. ft.
Area of base	=	50·27
		tons.
Pressure at base per square foot $= \frac{193}{50 \cdot 27}$ ..	=	3·84

Calculation showing weight to be supported by surface friction, deducting support derived from area of base at 5 tons per square foot:

		tons.
Total weight, as on previous page	=	318
Deduct support derived from base	=	252
To be supported by surface friction ..		66 tons.

Surface area, 622 square feet.

Pressure on surface per square foot, or required frictional resistance .. .. .. $= \frac{66}{622} = \cdot 106$ ton.

Note.—In the latter calculations the loss of weight of cylinder from immersion in water is omitted. The author thinks it advisable, in most instances, not to take into account this decrease of weight, as any support derived from this source must be liable to great fluctuation. It is evident from the foregoing that great exactness in the calculations is not required, as the support derived from the area of base of cylinder and surface friction must be assumed in great measure, and these data can only be safely arrived at by a careful investigation of the soil, and also by reference to similar works erected. A considerable margin of stability should in all cases be allowed, as from the nature of the calculations exact results cannot be obtained. *The area of the base* is the principal source on which the stability of a cylinder foundation depends, as this is generally unalterable, whereas the resistance from surface friction may be changed from scour of river, soakage of water, vibration, and other causes.

In a cylinder of large diameter the proportion of circumference (or surface area for one foot in height of cylinder) to the area of

the base is small. On the other hand, where a cylinder is of small diameter, the circumference (or surface area for one foot in height of cylinder) is nearly equal to the area of the base. For instance, in a cylinder 4′ 0″ in internal diameter, the internal area of the cylinder and the circumference (or surface area for one foot in height of the cylinder) are equal; whereas, in one of (say) 20′ 0″ diameter the area of the base is five times as much as the circumference (or surface area for one foot in height of cylinder). Therefore, it is advisable to allow a smaller coefficient for surface friction in cylinders of small diameter than in one, sunk in same soil, of large diameter, as the area of the base is the chief support.

In calculating the surface friction the total depth the cylinder is sunk in the ground can scarcely be taken as giving surface friction—the depth sunk in the solid ground alone can be relied upon; for it is obvious that as peat, slake, made ground, silt, and soils of that nature, cannot be considered a safe foundation without artificial means being applied, so no surface friction should be reckoned for their depth.

In increasing the depth to which a cylinder is sunk in the ground, if the soil is of same nature, the *total frictional resistance is alone increased.* The supporting power derived from the area of the base remains the same, and it should be borne in mind that, by increasing the depth to which the cylinder is sunk in the ground, the total weight of the cylinder is also increased in a corresponding ratio, and thus a greater strain is brought on the area of the base. Whether the frictional resistance per square foot increases according to the depth the cylinder is sunk into the ground is open to question, and therefore any supposed increased resistance per unit of surface area should be disregarded in calculating the supporting power of the cylinder. Probably, in loose soil, the frictional resistance does increase according to the depth the cylinder is sunk into the ground.

Although the actual depth to which a cylinder is sunk is seldom ascertained minutely beforehand, nevertheless it can be very closely arrived at by a complete system of borings and trial pits.

The horizontal flanges of the cylinder connect the concrete or brickwork with the iron rings, and thus the frictional resist-

ance may be taken into account in calculating the supporting power, although the superstructure does not rest on the iron rings.

The calculations on pages 7, 8, 9, and 10, by the aid of Tables "A" and "B," would be simplified as follows:

Approximate weight of cast iron in cylinder 8′ diameter, $1\frac{1}{2}''$ thick, 24′ high.

Table "B," Column 3, opposite 8′ diameter, $1\frac{1}{2}''$ thick:

·638 (weight in tons of cylinder per lineal foot) × 24′	=	tons. 15·31	

Ditto, $1\frac{1}{4}''$ thick:

·530 (weight in tons of cylinder per lineal foot) × 30′	=	15·90	tons. 31·21
Add 25 per cent. for joint flanges, ribs, &c.			7·80
Bracing frame to connect cylinders (say) ..			·99

Concrete, 8′ diameter.—Column 4, Table "A," we find opposite 8′ diameter:

tons. 9·17 (weight in tons of concrete in cement, per lineal yard) × 8	=	73·36

Brickwork, 8′ diameter.—Column 5, Table "A," we find opposite 8′ diameter:

tons. 7·55 (weight in tons of brickwork in cement, per lineal yard) × 10	=	75·50
Bedstones, &c. (say)		1·46
Weight of cylinder complete		190·32
Weight of superstructure and test load, as in previous calculation $= \frac{2\cdot62 \times 120}{2} = 157\cdot2$ tons (say)		157·68
Total weight on one cylinder, including its own weight and test load		348·00 tons.

SUPPORTING POWER.

From area of base, Table "A," Column 2, we find opposite 8′ diameter:

area. tons.		tons.
50·27 × 5	=	251·35

From surface friction, Table "B," Column 4, we find opposite 8′ diameter, and $1\frac{1}{2}''$ thick:

25·92 × 24′ × ·20	=	124·42

From immersion in water, Table "B," Column 5, we find opposite 8′ diameter, and $1\frac{1}{4}''$ thick:

1·474 × 7′	=	10·32
Total supporting power ..		386·09 tons.

EXPLANATION OF TABLES "A" AND "B."

Notation.

D = Internal diameter of cylinder, in feet and decimals of a foot.
O = External " " " " "
W = Weight, in tons and decimals of a ton, of cast iron in cylinder, per lineal foot of height of cylinder.
A = Surface area, in square feet and decimals of a square foot, in contact with earth, per lineal foot of height of cylinder.
L = Loss of weight, in tons and decimals of a ton, by immersion in water, per lineal foot of height of cylinder.
I = Internal area of cylinder, in square feet and decimals of a square foot.
C = Contents, in cube yards and decimals of a cube yard, per lineal yard of height of cylinder.
T = Weight, in tons and decimals of a ton, of concrete in cement, per lineal yard of height of cylinder.
B = Weight, in tons and decimals of a ton, of brickwork in cement, per lineal yard of height of cylinder.

TABLE "A."

Column 2 is calculated by the ordinary formula:

$$1 = D^2 \times \cdot 7854.$$

Column 3 is obtained as follows:

$$C = \frac{D^2 \times \cdot 7854}{9}; \text{ or, simplified, } C = D^2 \times \cdot 08727.$$

Column 4 is thus arrived at:

$$T = \frac{D^2 \times \cdot 7854}{9} \times 1 \cdot 64; \text{ or, simplified, } = C \text{ (given in Column 3)} \times 1 \cdot 64; \text{ or, in terms of the internal diameter, equals } D^2 \times \cdot 1432.$$

NOTE.—The weight of Portland cement concrete is taken at 136 lbs. per cube foot, or 1·64 tons per cube yard.

Column 5 is calculated as follows:

$$B = \frac{D^2 \times \cdot 7854}{9} \times 1 \cdot 35; \text{ or, simplified, } = C \text{ (given in Column 3)} \times 1 \cdot 35; \text{ or, in terms of the internal diameter, } = D^2 \times \cdot 1178.$$

NOTE.—The weight of brickwork in cement is taken at 112 lbs. per cube foot, or 1·35 tons per cube yard.

TABLE "B."

Column 3 is calculated as follows:

$$W = \frac{(O^2 - D^2) \times \cdot 7854}{5}; \text{ or, simplified, } = (O^2 - D^2) \times \cdot 15708.$$

NOTE.—The constant 5 is obtained by taking, for ease of calculation, the weight of a cube foot of cast iron at 448 lbs., which $= \frac{448}{2240} = \cdot 20 = \frac{1}{5}$th of a ton.

Column 4 is arrived at by the ordinary formula:

$$A = O \times 3 \cdot 1416.$$

Column 5 is obtained as follows:

$$L = O^2 \times \cdot 7854 \times \cdot 02786; \text{ or, simplified, } = O^2 \times \cdot 02188.$$

NOTE.—The constant ·02786 is the weight, in decimals of a ton, of a cube foot of fresh water.

TABLE "A."

Column 1 contains internal diameter of cylinder, in feet and decimals of a foot.

Column 2 gives internal area of cylinder, in square feet and decimals of a square foot.

Note.—The *internal* areas of the cylinder only are given, as they alone are required in calculating the sustaining power derived from the area of the base of the cylinder, as the weight of the bridge rests on the concrete and brickwork, &c., and not on the ironwork.

Column 3 gives the contents, in cube yards and decimals of a cube yard per lineal yard of height of cylinder.

Note.—The author has commenced the internal diameters of the cylinder at 4′ 0″ and has increased them by increments of 6″ to 21′ 0″. The former may be considered as nearly the least practical diameter of a cylinder foundation. Below this diameter the cylinder would partake more of the nature of a pile or column, being of *itself* the support to the superstructure of the bridge and not, as is the case in a cylinder foundation, merely the skin, as it were, *containing* the concrete, brickwork, &c., which actually supports the weight of the superstructure of the bridge. The latter dimension, viz. 21′ 0″, the author believes to be the largest diameter yet adopted in a cylinder bridge pier.

Note.—For ease of calculation the contents are given in cubic yards and decimals of a cube yard per lineal *yard* of height of cylinder, in preference to giving the contents in cube yards and decimals of a cube yard per lineal *foot* of height of cylinder, as brickwork and concrete are usually measured by the cube yard.

Column 4 shows the weight, in tons and decimals of a ton, of concrete in cement, per lineal yard of height of cylinder.

Column 5 gives the weight, in tons and decimals of a ton, of brickwork in cement, per lineal yard of height of cylinder.

Application of Table "A."

Column 3, when multiplied by the height of cylinder, in lineal yards and decimals of a lineal yard, will give the contents in cube yards and decimals of a cube yard.

Columns 4 and 5, when multiplied by the height, in lineal yards and decimals of a lineal yard, for which the cement concrete or the brickwork in cement extends, will give respectively their weight in tons and decimals of a ton.

TABLE "B."

Column 1 gives the internal diameter of cylinder in feet and decimals of a foot.

Column 2 contains thickness of cast iron in cylinder in inches.

NOTE.—The thicknesses of iron are taken from general practice, and are the least and the greatest thickness of cast iron in cylinder for the respective diameters; many of the thicknesses of metal are those adopted in existing examples.

Weight of cast iron, in tons and decimals of a ton per lineal foot of height of cylinder, equals approximately:

Thickness of iron in cylinder.			
¾″	.. ..	Internal diameter, in feet and decimals	× ·040
1″	.. ..	" " " "	× ·053
1¼″	.. ..	" " " "	× ·067
1½″	.. ..	" " " "	× ·080
1¾″	.. ..	" " " "	× ·094
2″	.. ..	" " " "	× ·106
2¼″	.. ..	" " " "	× ·119
2½″	.. ..	" " " "	× ·132

Add to the above weights for ribs, lugs or strengthening brackets, bosses, joint flanges, horizontal and vertical stiffeners, &c., 20 to 25 per cent.

Column 3 gives the weight, in tons and decimals of a ton, of cast iron in cylinder, per lineal foot of height of cylinder.

Column 3, when multiplied by the height of cylinder in lineal feet, will give the weight of cast iron in cylinder, in tons and decimals of a ton.

Column 4 contains surface area, in square feet and decimals of a square foot, in contact with earth, per lineal foot of height of cylinder.

Column 4, when multiplied by the depth in lineal feet the cylinder is sunk in ground, and by the frictional resistance of the ground per square foot of surface area of the cylinder, in decimals of a ton, will give the resistance due to friction, in tons and decimals of a ton.

Column 5 gives loss of weight, in tons and decimals of a ton, by immersion in water, per lineal foot of height of cylinder.

Column 5, when multiplied by the depth of water in feet at

the lowest tide or depth, gives the flotation power, or loss of weight from immersion of the cylinder, in tons and decimals of a ton.

NOTE.—This, in shallow rivers and where cylinder is of small diameter, may be disregarded for all practical purposes.

NOTES ON MASONRY, BRICKWORK, AND CONCRETE USED IN CYLINDER.

The courses of masonry should be kept as level as possible, so as to counteract any unequal settlement, as the work will settle most where the greatest number of joints occur.

Care should also be taken to evenly bed and cross the joints of the brickwork or masonry in the cylinder, so as to obtain equal bearing, and prevent any lateral strain; and it is necessary to make it as far as is practicable a monolithic mass, and this can be done to a very great extent by getting a good bond. The importance of attending to this will be readily understood when it is borne in mind that unless the hearting acts as one mass, the weight the area of the cylinder has to bear will not be distributed over the whole of the area of its base. This may be partly prevented by making the bedstones or roller beds for the girder extend over the whole area of the top of the cylinder, thus distributing the weight; and in order to attain this end, it is open to question whether hoop iron or some other material should not be built in with the brickwork and stonework.

The masonry or brickwork inside the cylinder should, when begun, be finished off; for if the cement is of good quality, the stones or bricks first laid become solidly united to each other, while some of the joints only just made are in a soft and compressible state, and therefore unequal settlement will probably occur, unless the work proceeds continuously.

Where a facing of ashlar, &c., is introduced, care must be taken to get a thorough bond between it and the body of the work, or the facing may peel away.

In masonry the stones should be placed on their natural beds.

Good cement only should be used, as the strength of the work greatly depends upon it.

In tide work, when concrete, &c., is deposited, it should be

carefully protected by means of a covering (if possible), as in all tidal rivers there is, more or less, a muddy deposit left at each tide, and it is necessary, to ensure sound work, that this deposit should be cleared off, either by flushing or scraping, before any fresh concrete is put on.

The concrete should not be thrown in from a great height, but should be just cast in and carefully punned.

Cement used where there is sea water should be unalterable and unaffected by any action of the sea water on it; and if concrete in a wet state is exposed to a current of water, the cement will be washed out.

As the concrete in the cylinder is in a considerable mass, and as it is covered up as soon as made, it is imperative that only quick setting material should be used, and that it should possess increasing powers of resistance.

If brickwork is used in the cylinder it cannot be built up quite closely to the iron rings; therefore liquid cement or cement grouting should be poured round the sides, so as to leave no unoccupied space.

All the materials employed should be of good quality, and be sound and hard.

Notes on Iron used in Cylinder.

As the strength of cast iron depends upon its rigidity, it is necessary to stiffen the cylinder rings by lugs or brackets, and vertical and horizontal flanges, which also form the joint flanges.

The joints should be made slightly stronger than the solid parts of the work, as they are subject to special defects, such as unequal bearing, &c.

The vertical and horizontal flanges of the cylinder should be well and firmly bolted together, as the lateral strength of the cylinder is thereby secured.

It may be as well in cylinders of small diameter to lessen the length of each ring and make them in one piece, thus obviating the necessity of any *vertical* joint flanges, and with the increased facilities and improved machinery now in use, many ironmasters will do this without any extra charge.

In tropical climates, where the atmosphere affects the metal to

a greater extent than in Europe, ample allowance in the thickness of the cylinder should be made.

There is greater liability to imperfections in the castings if the rings forming the cylinder are cast horizontally instead of vertically.

In increasing the thickness of the rings of the cylinder, the same unit of strength per square inch for the increased area does not hold, for beyond a certain thickness the value per square inch decreases very considerably.

The author would never use a less thickness of cast iron in the rings of the cylinder than 1 inch or a greater thickness than $2\frac{1}{2}$ inches, and this latter only as an exceptional case; and for the bottom ring, which, to facilitate the sinking, is generally brought to a taper.

Castings are generally made of greater thickness in practice than the requirements of theory show as necessary.

Cast iron is more liable to be broken by collision with floating substances than wrought iron.

It is usual when a bolt passes through a piece of cast iron, to increase the thickness of the metal at that point to a little beyond where the head or the nut of the bolt extends.

A bad joint will often not be discovered on testing a structure, but only after it has been subject to continuous strain and vibration; thus the importance of good and sound joints is evident.

It is advisable to make the bottom ring of the cylinder thicker than the other rings, on account of the greater cross strain, &c., it has to bear.

Much of the strength of a casting depends on the design. There should be as few abrupt bends, sharp angles, and sudden variations of thickness as possible, in order to obtain equal and uniform cooling, and accord in the order and direction of crystallization, as it has been found from experience that wherever the order of crystallization is disturbed there will be found weakness.

Increased thickness should not be considered as an equivalent to inferior iron, for in no material can it be said with greater truth, that it is absolutely necessary to have quality as well as quantity.

NOTES ON TIMBER.

Although timber is not employed in the permanent structure of an iron cylinder pier, nevertheless it is used largely in all bridgework for temporary purposes, and therefore a few remarks respecting it may not be considered out of place.

Timber may have the appearance of soundness exteriorly and yet be defective at the heart.

It is not sufficient to look to merely the gross strain that has been borne by the wood in experiments, and from these data alone to decide upon its use; but its toughness, its elasticity, its resistance to attacks of insects, its power of sustaining sudden shocks (if used in situations where there is shipping, or where floating débris is brought down by floods), should be considered, and the all-important point of its resistance to damp must be carefully investigated. Care should be taken that no sapwood is used, but that it is practically all heartwood; the point where the heartwood and sapwood join is generally evident in most timber.

Timber that is noted for durability does not of necessity possess great strength, although it may generally be considered an indication of strength.

A wood having considerable compressive strength does not necessarily possess the power of resisting a like tensile or transverse strain.

In designing work, the fibre of the grain should be placed in position of greatest resistance; timber is less able to bear a tensile strain across than with the grain.

Timber cut from trees grown in swampy or very wet soil may be considered more likely to possess less strength and durability than the same amount of material cut from timber grown on well-drained land.

Timber cut from young or very old trees, is not so strong as that taken from middle-age trees, or, as is technically called, trees felled at the "age of maturity." A tree cut too young contains much sapwood. In a tree cut too old the centre of the heartwood has generally begun to decay and become brittle.

Some timber may be durable when always wet, but when alternately wet and dry it may very rapidly decay.

In timber kept constantly wet it is doubtless to some extent softened, and therefore weakened, though experiments are wanting to confirm this opinion.

Iron in contact with timber in situations exposed to changes of temperature and weather, to a considerable extent accelerates the decay of the timber, therefore it is advisable to have as few bolts, screws, &c., as possible, and wherever it is necessary to have bolts, &c., washers should in all cases be inserted.

The timber used in foundations should be selected with great care and with an especial view to its durability.

General Remarks on Foundatigns, &c.

The stability of the superstructure of a bridge is dependent upon the foundations. It is therefore necessary to pay particular attention to this part of the structure. Great care should be taken in designing the details and in its general execution. The quantity and quality of the materials employed should never be limited with the idea of economy. The nature of the soil, the depths or thicknesses of the different layers or strata, should be ascertained, and attention should be directed to the effects of the atmosphere and water on the formation. A system of foundations giving great stability on one soil, may be found useless for that of another, hence great care should be taken to ascertain (especially in long viaducts) that the foundations will be on the same stratum, as different systems of foundations may have to be used, if the soil varies, in order to ensure *uniformity of settlement*, which may be said to be the keystone of the stability of a foundation. Practically, it is almost impossible to prevent some slight settlement; but this does not affect the security of the structure so long as that settlement or subsidence *is uniform*, and does not amount to an actual sinking.

In a country where great floods occur the changes of the river-bed must be ascertained before fixing upon the site for the piers. Where great quantities of sand and alluvial matter are swept down by floods, the depth of the foundations must be increased, and it is important to remember the effect caused by the obstruction of the piers and the scour arising therefrom, for which allowance must be made.

Where the foundations of the proposed site for a bridge are ascertained to be bad, it is advisable to put no thrust on the piers or abutments, but to keep the pressure simply insistent or perfectly vertical; and to secure this it is necessary to erect a girder and not an arched bridge, as in the case of a girder bridge the settlement of one pier or abutment would not affect the stability of the bridge, but would simply lower the girder at one end.

It may become a question to be decided, whether in some cases it is necessary to sink down to a solid foundation, if at a very great depth, especially if in still water, or where the river is very sluggish. It may be possible to so spread out the area of the foundations that it may be perfectly safe without going to the expense of sinking to a great depth. It is to be remembered that the deeper the foundation is sunk, the higher the piers become, and therefore a greater weight is brought on the base.

The height of piers, where very lofty, may determine the type of the superstructure, for it would be obviously unwise to erect any system giving thrust in such a case, for the strain on the piers should then be simply vertical.

Some types of bridges require more expensive piers than others. The piers of a suspension bridge must necessarily be higher than that of an arched bridge; and, again, the piers of an arched bridge must be made stronger than for a structure with a straight girder giving only downward pressure.

Where the foundations are bad they will govern the type of the superstructure, as the higher, wider, and more massive the pier, the more weight will there be on the area of the foundations, and therefore provision will have to be made for distributing this weight, and consequently it will entail greater expense.

In designing a pier where a heavy load has to be supported, it is advisable to place the weight to be sustained, as near as is practicable, in the centre, so as to prevent any unequal strain. By doing this no cross *strain* will be brought on the pier, but simply an insistent weight, which can only act perpendicularly to the surface of the earth.

The decrease of the weight of materials used in all submerged works should be remembered, for their specific gravity is lessened by the weight of the bulk of water displaced.

The stability of a foundation is dependent upon the law of action and reaction; for if the reaction of the ground is less than

the action of the weight superimposed, the foundation must fail. The unequal settlement of a foundation will alter the nature of the strains on a pier; and thus, if it was simply designed to withstand insistent weight, and that only, disastrous consequences might happen if any lateral or cross strain was put upon it.

The laws governing the stability of pillars or columns should be remembered in designing a cylinder foundation.

In comparing different systems of bridge construction with regard to their relative cost, it is necessary to bear in mind the question of the thickness of the abutments and piers for each distinct structure. Simply calculating the cost of the different systems of superstructure will not invariably show the economy of one type of structure over that of another. The cost of the superstructure of a bridge can be calculated very minutely, whereas that of the piers and abutments must to a certain extent be a matter of some doubt, more especially so with the piers. It may be found in some situations, even where stone is abundant, that the cost of putting in the foundations and erecting the piers to receive the thrust of an arched bridge will be so considerable, and the risk so great, that a girder bridge upon hollow cast-iron cylinders or screw piles will be necessary; and with regard to the latter system of construction, the work is always above water, much skilled labour is not required, few temporary materials are wanted, no cofferdams are necessary; and where the river has a strong current, and the bed is uneven, they are especially adapted. They can be completed in less time than masonry or brickwork piers, as there are no delays on account of weather; thus they give a more immediate return on the capital expended, which latter point is not the least to be considered. Again, should any of the piers of an arched bridge show signs of failure, the safety of the whole structure is impaired; but in the case of girders exerting no thrust, such as the lattice, plate, box, bow-string, Warren, &c., the piers simply having a vertical weight or downward pressure to sustain, if one fails, the whole structure is not impaired.

In rivers subject to very heavy floods it is necessary to contract the waterway as little as possible in order not to increase the scour, and screw piles and hollow cylinder foundations effect this object better than masonry or brickwork piers.

It may not be safe, in all cases, to determine the depth of

foundations and width of waterway from highest flood known, as provision in a doubtful case, or in a country subject to floods (especially those bringing down floating ice, and trees, &c.), should be made for even a higher flood, and the whole structure may, by a small increase in first cost, be saved from total destruction; and this increased depth of foundations and width of waterway should be regulated by a due regard to the effect of any failure of the structure. The bed of the river may be scoured out while the flood lasts, and yet be filled up as the flood subsides, and thus may seem to be perfectly secure, whereas really the scour may be increasing and deepening every flood.

When foundations are good, it will generally be found economical to have small spans and frequent piers; but where they are bad, large spans and few piers.

Small materials in bridgework tend to hasten completion of work on account of the greater ease with which they can be handled, but, on the other hand, large blocks add to the strength of the masonry, and it is a question, when plenty of tackle is at hand, which is the most economical.

In estimating the price of labour in a country not opened up, or where public works of magnitude have not been carried out before, it is certain that it will increase in a corresponding ratio with the demand, and therefore it may be advisable to design a structure requiring little skilled labour on the spot.

Where there are no good roads or facilities for transport by land or water to the site of bridge, it is necessary to bear in mind the element of portability, as it will in such cases greatly affect the cost of the structure.

A structure to be perfect should combine great strength, durability, and beauty of outline, for the least expenditure in money.

The surface friction of iron piles or cylinders per unit is less than that of timber piles, on account of the hardness, smoothness, and evenness of the surface of iron, as compared with the roughness and compressibility of wood. Therefore a coefficient per unit for the supporting power from friction on surface of a wooden pile will not be applicable to that of an iron one. This should be borne in mind in deciding upon the safe frictional load on surface of an iron cylinder.

The frictional resistance varies according to the soil in which the cylinder is sunk. Fine sand may be taken as giving a great frictional resistance on account of the smallness of the particles of which it is composed: it is nearly incompressible, but is not cohesive, and, practically speaking, becomes a fluid when exposed to much water, for it is moved by a gentle current. Gravel also gives great frictional resistance, and its condition is not changed by exposure to weather.

In soft, muddy earth or slake, the resistance from friction is practically *nil* till the cylinder is sunk to a considerable depth. Sand is good bearing strata: the same remark applies to compact gravel. It may be stated generally that the resistance from surface friction of the ground increases with the smallness of the particles composing soil of the nature of sand or gravel.

It is advisable to allow a fair margin of strength in a cylinder bridge on sand with railway trains passing over it at high velocities, as the vibration caused thereby may loosen the soil to some extent, and therefore lessen the support derived from the frictional surface.

The surface friction from cylinders sunk in the ground by internal excavation is probably not as much per unit as that of *driven* piles, on account of the driven piles having to compress on all sides the whole of the material driven through, whereas the cylinder is sunk by the material being excavated from its interior.

In some rivers, where scour is very great, it may be advisable to pile round pier, and throw in between the piles large stones, and then have the piles cut off so as to offer the least possible obstruction to waterway, and thus prevent any danger to navigation, also to allow floating ice, timber, &c., to pass.

It may happen that the material around surface of cylinder may be partly removed by scour, thus reducing the total frictional resistance of the cylinder. The area of the base should be considered the chief support in a cylinder foundation.

It does not necessarily follow, because a pile will not drive, or a cylinder will not sink, that solid ground is reached; for it may be only supported by the resistance of its frictional surface and not by the bearing support derived from the area of its base. Taking into consideration the *sudden* and violent manner in

which a pile is driven, and the *permanent* and even load it is afterwards called upon to support, it is possible that, under such circumstances, it may sink and cause appreciable settlement of the structure. This should be borne in mind in driving piles.

The coefficient of frictional resistance due to the exterior surface of cylinder adopted by English, American, and Continental engineers varies from 300 lbs. per square foot to half a ton; and the support derived from the area of the base of the cylinder, from four to eight tons per square foot, according to the nature of the soil.

It is usual in designing the cylinders for a bridge to enlarge or taper the cylinder. This should be done so as to offer the least possible obstruction or resistance to the flow of water, but yet to obtain increased area at the base, and consequently greater surface area. Taking these points into consideration, it appears that the best position for the commencement of this enlargement or tapering is just above ground line or bed of river; and as any increase of the diameter of the cylinder below the surface of ground will lessen the surface friction on that part of the cylinder situate above the point of such increased diameter, so the tapering should be commenced as before stated.

As the iron casing of the cylinder does not support any weight of itself, but simply *contains* the bearing support, and as it is the most expensive part of a cylinder bridge pier, it is evident that any improvement in this system of foundations will have for its object the removal of the iron rings.

The author thinks there is room for improvement in the joints generally adopted in bridge cylinders, as the weight amounts to a considerable percentage of the total weight of the cylinder, which, consequently, has so much more dead weight added to it.

The quantity of ice and floating timber passing down some rivers during winter renders it necessary to have piers of great weight and stability of construction. Some idea of the force with which masses of ice travel may be gathered from simply calculating the dead weight of the ice. For instance: Let a mass of ice be 100′ 0″ long, by 100′ 0″ wide, by 1′ 6″ in thickness (and this is no unusual size in Canada and the Northern climates), the weight in tons would be (taking a cube foot of ice at $58\frac{1}{2}$ lbs. weight):

$100 \times 100 \times 1 \cdot 5 = 15{,}000$ cube feet $\times 58\frac{1}{2}$ lbs. $= 877{,}500$ lbs. $=$ say, 392 tons; and this without taking into consideration the force of the current. It is thus evident that due regard must be paid to the solidity and weight of the piers in such situations.

In driving piles and sinking cylinders in sand or silt, they should be very rapidly done, so as to prevent ground from settling round them; and in the case of cylinders, to prevent the soil rising at the bottom.

A method used by the Hon. W. J. M'Alpine, in the Haarlem Bridge, United States, to gain increased area of base, was as follows:—To mine under and outside the cylinder, and extend the concrete two feet or so around base of cylinder, thus increasing the bearing power considerably.

In a foundation point of view, a girder giving no thrust may be considered as possessing a decided advantage over those producing thrust, as the piers in the former case need not be so thick and massive, as they have only to sustain an insistent weight.

A few piles *by themselves* have scarcely any lateral stiffness; but when well braced and connected together, they become uniformly resisting, and one can hardly yield without the others. Two piles, if thoroughly braced and connected together, may be safely assumed to bear more than the two piles taken separately, though experiments are wanting to determine this addition of strength.

Where ground is of a very soft, semifluid character, or of a rocky nature, care is required to secure cylinders and piles properly.

It has been suggested that in a quicksand it might be possible to harden it by sinking perforated pipes, and injecting through them cement, &c., and thus obtain a firm foundation. If practicable, it would doubtless be of use, especially in cases where a stratum of a treacherous nature occurs in otherwise good soil.

The author thinks that, in abstract, where the spans of a river bridge need not be above from 40 to 60 feet, foundations on screw piles will be cheapest; and where spans are longer than the above, that iron cylinder foundations are the best.

It is open to consideration whether the iron cylinder casing should stop at low-water level, or be carried up to underside of

girder, for the masonry or brickwork can be built up between tides, in the case of a tidal river.

In pure sand, and soils of a sandy nature, the system of well foundations adopted in India might be found to be more economical than a pier formed of hollow cast-iron cylinders.

It appears to the author that the plan invented by Mr. Brunlees, M.I.C.E., of sinking piles in sand by means of a water jet is one that might be employed with very great advantage, in most situations, to facilitate the sinking of cylinders; for the application of water pressure tends to unbind and loosen almost every soil.

The impracticability of laying down rigid laws on such a subject as foundations is apparent. It is only by experience, judgment, synthetic skill, and perseverance that the difficulties attending them can be overcome. We are fortunate in having as a guide the many noble works erected by the members of the Institution; not that we should be mere copyists, but that, by studying their works, we should be led to search out new paths of science, and thus bring fresh knowledge to our aid; for it is only by so doing we can hope to fulfil the especial mission of an Engineer, namely, that of utilising Nature's gifts, and making the seemingly impossible, possible.

TABLE "A."

No. 1. Internal diameter of cylinder in feet and decimals.	No. 2. Internal area of cylinder in square feet and decimals.	No. 3. Contents, in cube yards and decimals per lineal yard of height of cylinder.	No. 4. Weight, in tons and decimals, of concrete in cement per lineal yard of height of cylinder.	No. 5. Weight, in tons and decimals, of brickwork in cement per lineal yard of height of cylinder.
4·00	12·56	1·40	2·30	1·89
4·50	15·90	1·77	2·90	2·39
5·00	19·64	2·18	3·57	2·94
5·50	23·76	2·64	4·33	3·56
6·00	28·28	3·14	5·15	4·24
6·50	33·19	3·69	6·05	4·98
7·00	38·49	4·28	7·02	5·78
7·50	44·18	4·91	8·05	6·63
8·00	50·27	5·59	9·17	7·55
8·50	56·75	6·31	10·35	8·52
9·00	63·62	7·07	11·60	9·54
9·50	70·89	7·88	12·93	10·64
10·00	78·54	8·73	14·32	11·79
10·50	86·59	9·62	15·78	12·99
11·00	95·04	10·56	17·32	14·26
11·50	103·87	11·54	18·93	15·58
12·00	113·10	12·57	20·62	16·97
12·50	122·72	13·64	22·37	18·41
13·00	132·74	14·75	24·19	19·91
13·50	143·41	15·91	26·09	21·48
14·00	153·94	17·11	28·06	23·10
14·50	165·13	18·35	30·09	24·77
15·00	176·72	19·64	32·21	26·51
15·50	188·69	20·97	34·39	28·31
16·00	201·06	22·34	36·64	30·16
16·50	213·83	23·76	38·97	32·08
17·00	226·98	25·22	41·36	34·05
17·50	240·53	26·73	43·84	36·09
18·00	254·47	28·27	46·36	38·16
18·50	268·81	29·87	48·99	40·33
19·00	283·53	31·51	51·68	42·54
19·50	298·65	33·18	54·42	44·79
20·00	314·16	34·91	57·26	47·13
20·50	330·07	36·68	60·16	49·52
21·00	346·36	38·48	63·11	51·95